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REPORT OF THE PLASMA PHYSICS AND ENVIRONMENTAL  
PERTURBATION LABORATORY (PPEPL)  
WORKING GROUPS

Volume II – Wave Experiments Working Group

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16. ABSTRACT  <p>The area of wave experiments for the PPEPL is considered in broad terms. It is found that most experiments in this area can be classified typically by a few generalized experiments. These experiment possibilities are discussed in terms of advantages, disadvantages, and probable areas for future investigation. It is concluded that the areas where wave experiments have the most promise are wave sources, wave propagation, and nonlinear interactions and should be implemented in that order. It is recommended that the PPEPL facility remain sufficiently flexible to handle new ideas as they appear, and a continuing effort should be made to solicit new ideas and approaches. It is also felt that detailed investigations should begin as soon as possible in the areas of antennas, both conventional and particle types, and wave-particle interaction experiments.</p>					
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## PREFACE

In December 1971, OSS/MSFC initiated a study to determine the feasibility of carrying out active (perturbation) experimental studies of the ionospheric/magnetospheric plasma, as well as laboratory plasma studies, from a manned orbiting laboratory facility housed in a Spacelab module and carried into orbit by the Space Shuttle. This proposed facility has subsequently become known as the Plasma Physics and Environmental Perturbation Laboratory (PPEPL). The scientific community responded to this idea in a number of different areas, and it became apparent that the general study, being carried out by TRW Systems, Inc., and an associated science advisory board, could not address all of the aspects of each individual area. For this purpose working groups were organized in the three general areas of plasma probes, wakes, and sheaths; wave experiments; and magnetospheric studies. The specific purpose of the Wave Experiments Working Group was to investigate experimental concepts which involve waves, both in their generation and their interaction with the plasma.

In addition to the contributions of individual working group members, a major source of information used by the working group on wave experiments was the TRW compilation of experiment concepts.

The reports from each of the three working groups are printed as separate volumes. This volume is an edited version of the report written by the Wave Experiments Working Group. Volumes I and III are the reports prepared by the Plasma Probes, Wakes, and Sheaths Working Group and the Magnetospheric Experiments Working Group, respectively.

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## VOLUME II - WAVE EXPERIMENTS WORKING GROUP

### I. INTRODUCTION

For many years the plasma environment of the earth has been investigated by studying its effect upon various waves, both those traveling through it and those being reflected from it. The presence of the ionosphere was, in fact, first detected by its reflection of radio waves and the resultant long range propagation. The behavior of the bottomside ionosphere is still routinely measured through these reflection properties by ionosondes all over the world. Another example is the observation of whistlers generated by lightning in one hemisphere and traveling outward over large distances from the earth before being refracted back into the opposite hemisphere. Such measurements as these have led to their use as diagnostics for measuring ionospheric properties and as checks on some of the fundamentals of wave propagation in plasmas.

With the arrival of satellites for scientific purposes, it was natural to extend the previous thinking to the new possibilities which had opened up. For example, in the case of ionosondes, the unattainable region above the peak in electron density at a few hundred kilometers altitude could be investigated by placing an ionosonde well above that level and reflecting from below, hence, topside sounders. Similarly, with receivers of lower frequencies aboard spacecraft, observations of whistlers and other waves could also be made at these altitudes. In at least the earlier cases, the experimental objectives were simple extensions of the previous ground-based studies, the satellites affording the opportunity of making similar measurements in heretofore inaccessible regions.

A striking feature of these experiments on spacecraft was not this simple extension, however, but the whole host of new, additional phenomena which were observed. Most of these new observations can be attributed to the fact that the instruments are located in the ionospheric-magnetospheric plasma itself, opening up access to waves peculiar to a plasma, as well as those which are shielded from the ground. These observations have, again, led to their use as both diagnostics and experiments in basic plasma physics. The ionosphere-magnetosphere, in fact, turns out to be a rather good plasma for several types of investigations. Its advantages lie in its stability, its homogeneity over fairly large volumes, the lack of collisions for some cases, and its interesting anisotropy (comparable plasma and cyclotron frequencies). There is also a sufficient variation, spatially and temporally, to provide some variety in plasma properties in the latter case.

Satellite experiments seem, then, to be useful in terms of their applications to plasma physics as well as to geophysics. However, they are not without their drawbacks when compared to ground-based observations and laboratory experiments. These include the obvious compromises in areas such as weight, power, expense, the antennas which are possible, and the limitations imposed by the necessity of telemetry. A less obvious drawback, but one of great importance, is the inflexibility in the experimental procedures; this is caused by the long design lead times prevalent in satellite programs. The advantages and disadvantages of satellite research can be summarized as follows:

1. Advantages

- a. In situ measurements.
- b. Accessibility to many regions of space.
- c. Accessibility to phenomena.
- d. Variations in plasmas encountered.
- e. Homogeneity and size of plasma.
- f. Elimination of some boundaries.

2. Disadvantages

- a. Weight, size, and power limitations.
- b. Cost.
- c. Telemetry.
- d. Data handling and reduction.
- e. Experimental inflexibility.
- f. Lack of control over plasma.
- g. Perturbations on the plasma.
- h. Motion through the plasma.
- i. Spacecraft interference.



It would be of obvious benefit to reduce or eliminate the above disadvantages while retaining the advantages; this capability is enhanced with the advent of the Shuttle.

The proposed Plasma Physics and Environmental Perturbation Laboratory (PPEPL), a module payload under consideration for the Shuttle, introduces a number of possibilities for wave experiments in the ionospheric-magnetospheric plasma. The weight, size, and power limitations can be eliminated in some cases and reduced in all. The telemetry and data problems are less important because of the possibility of data handling, processing, and reduction on board; trained experimenters on the PPEPL can help in this regard. With a planned mission duration of 7 days and a turnaround of 6 months, it should be possible for trained experimenters to quickly revise experiments, procedures, and/or instruments to take advantage of previous observations.

The PPEPL will not solve all of the problems in satellite research and will introduce a few of its own. The high cost will not be eliminated but, hopefully, will be reduced. Some small control over the plasma may exist in the alterability of the Shuttle orbit but this will still limit the possibilities of many experiments. In fact, the limits on Shuttle orbits will be the largest drawback in some experimental areas. Motion through the plasma remains, as does the perturbation caused by the Shuttle. The latter may be alleviated by controlling the Shuttle attitude but will also be degraded by the extra outgassing from the life support systems which will be present. The interference due to the spacecraft can be minimized in many areas, but one problem which will be severe is the wave reflection properties of the Shuttle. Previous satellite experiments concerning waves have involved vehicle sizes (excluding antennas) no larger than and usually much smaller than the wavelengths involved. The physical size of the Shuttle could make it act as a good reflector in many wave experiments and this possibility should be considered.

The PPEPL offers, then, some significant improvements over previous satellite research but is not without drawbacks. Previous experience suggests that it is important not only to plan ahead to maximize the anticipated results and to minimize the disadvantages but also to allow some room for those unexpected observations which so often turn out to be more interesting than the original idea. Furthermore, it would seem insufficient to consider the PPEPL as an opportunity to do previously attempted experiments in a better or more thorough manner. If approached as a new tool in plasma physics and geophysics, the PPEPL may attract ideas which are not normally associated with space research. Thus, the area of waves in plasmas should be considered in terms of its possibility for good experimentation, either in the sense of basic physics or of geophysics, and of its advantages and disadvantages.

This report is based upon the findings of a work-study group formed for the purpose of evaluating the PPEPL program in terms of wave experiments. The consensus was that such a group could provide a more detailed evaluation than could the PPEPL advisory board, whose purpose was to comment on the overall design and planning responsibility contracted to TRW Systems Group.

The TRW approach was to solicit opinions and suggestions from the scientific community, and then to use the responses as a basis for designing the laboratory. The preliminary results of the TRW analysis were, in turn, used as a basis for the investigation by the waves study group, and many references are made to the TRW report\* (hereafter referred to as the redbook). Although many of the individual responses contained in the redbook are mentioned in this report by the redbook identification, it was not felt appropriate at this time to consider very specific ideas. Hence, individual proposals are not considered.

An attempt was made in this report to treat the wave experimental areas in broad but, hopefully, inclusive terms. Of all the possible areas for wave experimentation, significant interest has been expressed in several, and most individual experiments can be classified typically by a few generalized experiments. This current status for the experimental possibilities is discussed in terms of the advantages and disadvantages, and then probable areas for future investigation are considered.

## II. AREAS OF EXPERIMENTAL INTEREST

To illustrate the possible areas of experimental interest for the PPEPL, it is helpful to divide plasma physics into its natural categories. These can be outlined under the heading of PPEPL, itself presumably one of several Shuttle laboratories, as shown in Figure 1. Each of these categories and their relationships are defined only in the sense of the main emphasis of the experimenter's interest. In most experiments the areas cannot be isolated so easily, but the diagram does help to point out the possibilities in at least the area of waves.

A plasma consists of a system of particles and fields, and this forms a natural and relatively equal division. The area of particles has not been considered further in the diagram since it is not of intrinsic concern in this report;

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\*TRW Systems, Inc.: Candidate Experiment Synopses for the Plasma Physics and Environmental Perturbation Laboratory. TRW Report 21390-6003-R0-00, July 1972.

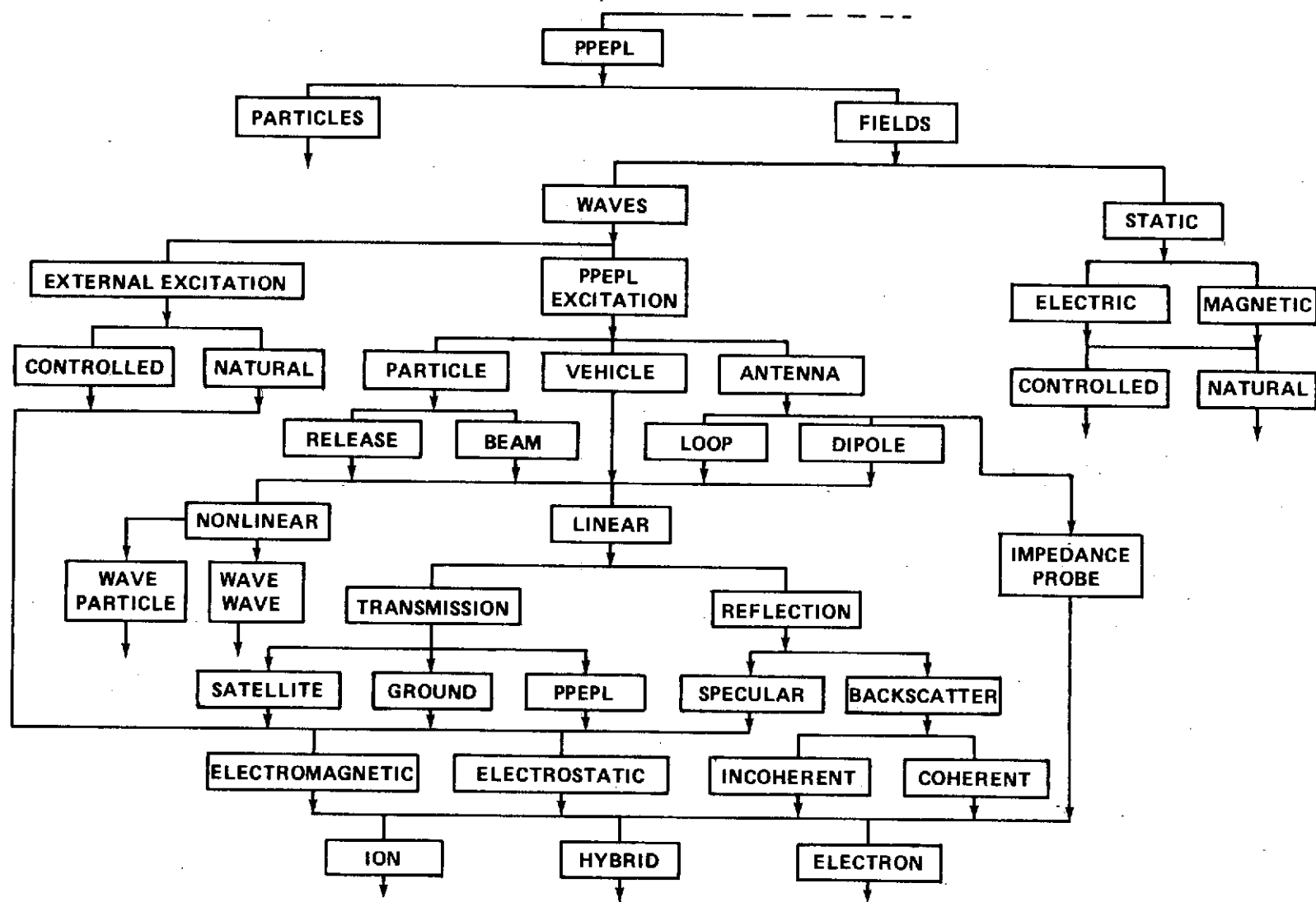


Figure 1. Natural categories of plasma physics.

presumably, this will be treated by the other groups. However, it is not meant to be implied that particles are not important in the consideration of wave experiments. Again, only those categories where the experimental interest is in the wave properties are relevant here.

The subheading of fields divides easily into those of static fields and waves. Static fields, both magnetic and electric, are present in the ambient plasma and will also be affected by the presence of the Shuttle. Measurement of the background magnetic field is important in terms of its contribution to other experiments, since the plasma properties are highly dependent on it. Natural electric fields in the ionosphere and magnetosphere are not normally important in their effect on waves but are extremely important geophysically and could also gain in importance as wave experiments are refined. Fields due to the presence of the PPEPL, both magnetic and electric, can be highly undesirable as a perturbation to other experimental techniques. Thus, the PPEPL (and the Shuttle) should have as little electric and magnetic effect as possible. If, however, such fields are controlled, they can be a source of experimentation in themselves. An example would be the cancellation of the geomagnetic field. Again, though, the interest here is in the area of waves, and the remainder of the discussion will be concerned with this aspect, the other areas in static fields and particles being considered only as they are specifically relevant.

As is the case with the static fields, wave fields may be characterized as externally excited (natural or controlled) or as caused by the PPEPL, intentionally or not. Measurements of naturally occurring waves, as well as those from controlled sources, have been carried out as passive experiments for many years on satellites. The PPEPL does not offer, in general, the possibility of a significant improvement over previous experiments except in the area of antennas and in data handling. An obvious possibility is to increase the size and complexity of the antenna(s). Because of reasonably large separation distances made possible through the use of booms, it may also be practical to perform interferometric studies on a single vehicle. The purpose of measuring the naturally occurring waves would be either as a diagnostic, determining plasma properties from the wave characteristics, or as a more basic experiment if the origin of the waves in the ionosphere-magnetosphere can be deduced. Although the motivation behind the PPEPL lies in the active experiment areas, it would seem entirely reasonable to include the observation of natural waves as a contributing discipline. In any case, naturally occurring waves will be a source of perturbation (noise at least) to other experiments and should be taken into account. Furthermore, all the equipment and instrumentation necessary for natural wave experiments will probably be available

as a subset of that necessary for the active experiments, thereby placing no additional burden on the facility except in terms of the available time and, possibly, in the area of sensitivity.

The remainder of the experimental areas comes under the subheading of active wave experiments, the primary purpose of the PPEPL with respect to fields. The first consideration in active wave experiments is the method of generating the waves. Waves that are generated by the motion of the PPEPL through the plasma (as may happen in the wake) are probably of greater interest to those involved directly with the vehicle-plasma interaction and can be treated in a manner similar to natural wave observations. The controlled generation of waves can be carried out either by antennas in the conventional sense or by changes in the ambient plasma through the introduction of particles. Assuming that a wave can be generated, the interest lies in either its propagation properties or its interaction properties with the medium, usually nonlinear. In each case there are electromagnetic and electrostatic waves, and their characteristics, in turn, may depend mainly on the electrons or ions or, in some cases, both (hybrid case).

The breakdown in the diagram should not be taken as complete in any sense. Neither should the order be considered as representative of the importance of each area. In some cases there is an established need for a particular type wave but no established method of generating it in any practical manner. Conversely, there may be a number of waves which are easily produced by antennas, but may not have been considered in terms of their possible contributions. In the cases where nonlinear effects are of interest, there is even a problem of whether they are products of the waves in the ambient plasma or antennas in the plasma. It would seem reasonable, then, to treat the areas of the wave properties and of their generation in parallel. If the products of traditional antennas and the desirability of using various types of waves are each determined, the area of overlap will constitute an obvious source of the most easily obtained results. The exclusive areas might then need further investigation in a manner which takes into account the difficulties involved, either in obtaining the wave or in how to use it.

The first step is to look at each of the promising areas as individual subjects without regard to the problems in those other areas that will necessarily be involved. There are three topics that seem to be the most interesting in terms of a balance between a reasonable amount of previous, interpreted experience and a sufficient number of unanswered but interesting questions. These three areas are those of waves propagating in plasmas, nonlinear interactions, and the methods for producing waves. In Figure 1 these consist of parts of the categories linear, nonlinear, and PPEPL excitation.

## A. Wave Propagation Experiments

The fundamental principle for any propagation experiment is that a wave traveling between two points will be affected in some measurable and predictable manner by the plasma. In cases where the wave behavior is well understood, the measurement may be interpreted as a plasma diagnostic, while, if the plasma properties are otherwise known, the measurement may indicate the properties of the wave. Three types of experiment are possible in this area:

1. Transmission experiments, either from antenna to antenna on the PPEPL or from the PPEPL to a subsatellite or the ground and vice versa.
2. Reflection experiments, with both transmitter and receiver on the PPEPL and specular reflection in the medium.
3. Backscatter experiments, with both transmitter and receiver on the PPEPL and scattering from various particles in the plasma.

Many suggestions for experiments have been included in the TRW redbook concerning the first two cases but none for the third.

To appreciate the large number of possibilities which can be involved even in these few areas, one need only look at the variety of waves which can propagate in a plasma at given wave frequencies and for various plasma parameters. This is illustrated in Table 1 which contains a list of these modes for each frequency regime in a plasma of electrons and a single ion. The frequencies referred to in the table are defined below:

$\omega$	wave frequency
$\omega_p$	plasma frequency
$\Omega_e$	electron cyclotron frequency
$\Omega_i$	ion cyclotron frequency
$\omega_{XR}$	cutoff frequency for the X-R mode
$\omega_{XL}$	cutoff frequency for the X-L mode
$\omega_{OX}$	exchange frequency for the O and X modes

$\omega_{UH}$	upper hybrid resonance frequency
$\omega_{LH}$	lower hybrid resonance frequency

The nomenclature for identifying each of the modes is in the usual form applied to wave-normal or phase velocity surfaces. In the case of the electromagnetic (EM) waves, the ordinary and extraordinary modes O and X, propagate across the background magnetic field, while the left- and right-hand polarized modes, L and R, propagate along the field. A wave identified as L-O, for instance, signifies a wave that is left-hand polarized when propagating along the field, an ordinary wave when propagating across the field, and one which goes from one characteristic to the other around some intermediate angle.

The electrostatic (ES) modes are identified simply by whether they are predominantly electron controlled or ion controlled. In some cases the wave surfaces are purely electron or ion dominated for all propagation angles; in some they are electrostatic for propagation either along or across the field and become electromagnetic at an intermediate angle; in others they are either electron or ion along the field and ion or electron across the field; and in still others they are electron or ion along or across the field, electromagnetic across or along the field, and ion or electron in a region around some intermediate angle.

Table 1 is not complete, even for the conditions stated. The Bernstein modes, electrostatic modes which propagate in passbands bounded in part by multiples of the ion and electron cyclotron frequencies and coupled to the hybrid resonances, have been omitted for clarity and because there are an infinite number of these modes. The situation can be further complicated by adding additional ions, a probable situation for the PPEPL. For each ion one can add an extra cyclotron frequency, hybrid resonance frequency, and cutoff frequency. This provides a number of additional frequency regimes and they give many of the same modes plus the additional features of another ion-electron coupling and an ion-ion coupling. Since each of the modes depends upon particular qualities of the plasma, it is easy to see why so much can be learned from the behavior of waves in plasmas and why almost all of the modes mentioned here have been suggested as of interest in the redbook examples. It is also easy to see why a good deal of confusion can exist.

If this list of some of the possible modes is considered just as a simple illustration, several points can be made without a thorough understanding of any of the details involved. The most obvious is that waves exist at all frequencies. Another is that there may be and most likely is more than one wave

TABLE 1. WAVE PROPAGATION IN A PLASMA  
OF ELECTRONS AND A SINGLE ION

Frequency Regime	Mode	
	Electro- magnetic	Electrostatic
$\omega > \omega_{XR}$	L-O, R-X	electron, ion
$\omega_{XR} > \omega > \omega_{UH}$	L-O	electron, ion
$\omega_{UH} > \omega > \omega_p$ and $\Omega_e$	L-O, X	ion, electron coupled to X
$\omega_p > \omega > \omega_{XL}$ and $\Omega_e$	L-X	ion
$\omega_{XL} > \omega > \Omega_e$		ion
$\Omega_e > \omega > \omega_p$ and $\omega_{OX}$	L-O, R-X	ion, coupled ion-electron
$\omega_{OX} > \omega > \omega_{XL}$	L-X, R-O	ion, coupled ion-electron
$\Omega_e$ and $\omega_p > \omega > \omega_{XL}$	L-X, R	ion, coupled ion-electron also coupled to the R
$\Omega_e$ and $\omega_p$ and $\omega_{XL} > \omega > \omega_{LH}$	R	ion, coupled ion-electron also coupled to the R or ion coupled to the R
$\omega_{XL} > \omega > \omega_p$ and $\omega_{LH}$	R-O	ion, coupled ion-electron
$\omega_{LH} > \omega > \Omega_i$ and $\omega_p$	R-O, X	ion, coupled ion-electron also coupled to the R or ion coupled to the R
$\omega_{LH}$ and $\omega_p > \omega > \Omega_i$	R-X	ion
$\Omega_i > \omega > \omega_p$	R-O, L-X	ion, coupled ion-electron
$\Omega_i$ and $\omega_p > \omega$	R-X, L	ion, coupled ion-electron also coupled to the L or ion coupled to the L



which is possible at a given frequency in a given plasma. A third involves the difference in character for a wave propagating either along or across the field and also at intermediate angles. Problems can arise because of this multiplicity. It becomes necessary to know not only the wave frequency and the natural frequencies of the plasma in order to identify a frequency regime but also something about the propagation vector in order to identify the actual wave itself. Exciting a desired wave at a given frequency amounts to more than simply putting a lot of energy into the plasma at that frequency. It must account for the possibility of other waves (or even the same wave at a different propagation angle) soaking up all the power. Finally, as might be suspected from the complexity, the theoretical treatment can be quite difficult. Practical solutions for the dispersion relations are known only for special cases, usually exactly along or across the field, and this is also true for many of the areas covered by laboratory experiments. Hence, new experimental evidence could not only confirm theory but also provide solutions in unknown regions.

Transmission experiments consist of a wave propagating between a source at one point and a receiver at another. One can presumably learn about a particular wave or some plasma property by measuring the time of propagation, the wave direction, or the received amplitude or phase. Such experiments have been carried out in laboratory plasmas but usually under very stringent and ideal conditions. Those previously performed in the ionosphere-magnetosphere have been long-range transmission, such as Faraday rotation experiments or the observation of whistlers. A digest of those proposals in the TRW redbook which would involve waves propagating from a source to a remote receiver, whether that is the primary source of interest or not, is given in Table 2, where it is assumed that all of the sources are on the PPEPL, unless otherwise stated. Cases in which a nonlinear interaction in the plasma gives a difference wave have been treated as two transmission problems.

The large number of examples illustrates the fact that a knowledge of propagation properties will be an essential feature of many experiments and does not show a preference for transmission experiments. Those experiments whose primary purpose is the measurement of the transmission properties, as applicable to either propagation theory or diagnostics and identified with respect to their transmission paths, are listed in Table 3 for a variety of frequencies. However, most fit into two general types of experiments.

The first type is the transmission of electrostatic waves between two antennas in the plasma. Included in this group are at least WC-1, WC-8, WC-9, WC-18, WC-20, WC-24, WC-34, WS-22, and PP-1. A pulse is generated at one antenna with a particular frequency. If the plasma between the antennas

TABLE 2. EXPERIMENTS INVOLVING TRANSMISSION

Redbook Identification	Source	Receiver	Wave	Interest
BP-2	Beam, injections	PPEPL, ground, rockets	VLF	Diagnostic
BP-7	Beam	PPEPL	ES, EM	Beam characteristics
BP-9	Beam	PPEPL	ULF-ELF	Diagnostic
BP-14	Beam	PPEPL	Plasma waves	Beam instability
BP-19	Beam	PPEPL	ES, EM	Beam stability diagnostic
BP-21	Natural	PPEPL	ES, EM	Diagnostic
BP-22	Beam	PPEPL	ES, EM	Beam stability
BP-23	Beam	PPEPL	1Hz-20MHz	Beam turbulence
BP-24	Beam	PPEPL	VLF-RF	Wave-particle
WP-1	Transmitter	Plasma	Whistler	Wave-particle
WP-2	Natural	PPEPL		Diagnostic
WP-3	Transmitter	Plasma	RF	Nonlinear
WP-3	Plasma	PPEPL	VLF	Nonlinear
WP-4	Transmitter	PPEPL, subsatellite	VLF	Irradiation
WP-5	Natural	PPEPL		Diagnostic
WP-6	Natural	PPEPL rockets	VLF	Diagnostic
WP-7	Transmitter	Ground	LF-VLF	Communications
WP-7	Ground transmitter	PPEPL	LF-VLF	Communications
WP-8	Natural	Subsatellite	VLF	Diagnostic
WP-9	Transmitter	Plasma	VLF-HF	Wave-particle
WP-9	Plasma	PPEPL	VLF-HF	Wave-particle
WP-10	Beam	Subsatellite, ground	ELF-VLF	Irradiation
WP-11	Beam	PPEPL	VLF	Irradiation
WP-12	Transmitter	Plasma	VLF	Wave-particle
WP-13	Transmitter	Plasma	EM	Nonlinear
WP-14	Transmitter	Plasma		Wave-particle
WP-15	Explosive charge on rocket	PPEPL		Diagnostic
WP-18	Beam	PPEPL	ULF	Irradiation

TABLE 2. (Continued)

Redbook Identification	Source	Receiver	Wave	Interest
WC-1	Transmitter	Subsatellite	ES	Diagnostic
WC-2	Transmitter	Plasma	RF	Wave-wave
WC-2	Plasma	PPEPL or subsatellite		Wave-wave
WC-3	Transmitter	Plasma	RF	Wave-wave
WC-3	Plasma	Subsatellite		Wave-wave
WC-6	Transmitter	PPEPL	< 1 Hz	Irradiation
WC-7, PP-10	Transmitter	Subsatellite	VLF-HF	Delayed echoes
WC-8, PP-11	Transmitter	PPEPL	RF, ES	Diagnostic
WC-9	Transmitter	Subsatellite	RF, ES	Dispersion relations
WC-12	Natural	PPEPL	Hydro-magnetic	Diagnostic
WC-13	Transmitter	Plasma	RF	Nonlinear
WC-13	Plasma	PPEPL	VLF	Nonlinear
WC-14	Transmitter	Ground	< 100 Hz	Diagnostic
WC-14	Natural	PPEPL	< 100 Hz	Diagnostic
WC-15	Transmitter	Ground	SUB-LF	Communications
WC-17	Transmitter	Ground	0.01 Hz-20 MHz	Propagation
WC-17	Ground transmitter	PPEPL	0.01 Hz-20 MHz	Propagation
WC-18	Transmitter	PPEPL or subsatellite	ES	Propagation
WC-19	Subsatellite	PPEPL	0-20 MHz, EM	Propagation
WC-20, PP-8	Transmitter	PPEPL	Cyclotron harmonic	Propagation
WC-20, PP-8	Transmitter	PPEPL	Pulse	Wave packet
WC-20, PP-8	Transmitter	Plasma		Wave-wave
WC-20, PP-8	Plasma	PPEPL		Wave-wave
WC-21	Natural	PPEPL	ES ion	
WC-22	Transmitter	Ground	VLF	Propagation
WC-22	Ground transmitter	PPEPL	VLF	Propagation
WC-23	Transmitter	Plasma	VLF-HF	Wave-wave
WC-23	Plasma	PPEPL	VLF-HF	Wave-wave
WC-24	Transmitter	Subsatellite	Plasma waves	Dispersion relations
WC-25				Propagation
WC-27			Plasma oscillations	Attenuation

TABLE 2. (Concluded)

Redbook Identification	Source	Receiver	Wave	Interest
WC-28	Natural	PPEPL, ground	mm wave-length	Sheath transmission
WC-29			VLF, ELF, ULF	Diagnostic
WC-31			Plasma waves	Propagation
WC-33			Alfvén waves	Propagation
WC-34	Transmitter	Subsatellite		Damping
WC-35	Transmitter	PPEPL	VLF	Irradiation
WS-7	Transmitter	PPEPL	Near resonances	Diagnostic
WS-18	Transmitter		Low phase velocity	Diagnostic
WS-25	Transmitter	PPEPL	ES	Diagnostic
WS-28	Transmitter	Plasma	100 kHz-3 GHz	Wave-wave
WS-28	Plasma	Subsatellite	100 kHz-3 GHz	Wave-wave
MM-1	Ground transmitter	Plasma	RF	Heating
MM-2	Transmitter	Subsatellite, ground	VLF	Diagnostic
MM-4	Beam, injection	PPEPL		Wave-particle
MM-5	Transmitter	Plasma	Near plasma resonance	Nonlinear
MM-5	Plasma	PPEPL		Nonlinear
MM-7	Release	PPEPL	ES	Diagnostic
MM-10	Release	PPEPL	VLF	Diagnostic
MM-11	Transmitter	Plasma	EM	Nonlinear
MM-11	Plasma	Subsatellite		Nonlinear
MM-12	Transmitter	Plasma	VLF	Wave-particle
MM-14	Ground transmitter	Plasma	RF	Heating
MM-16	Transmitter	Plasma	Alfvén	Heating
MM-20	Transmitter	Plasma	RF	Heating
PP-1	Transmitter	Subsatellite	Cyclotron harmonic	Diagnostic

TABLE 3. TRANSMISSION EXPERIMENTS

	Boom ↔ Boom	PPEPL ↔ Subsatellite	PPEPL ↔ Ground
Propagation Theory	WP-4	WP-4	WC-14
	WC-18	WP-15	WC-17
	WC-19	WC-7, PP-10	WC-22
	WC-20, PP-8	WC-9	WC-28
		WC-19	
		WC-24	
Diagnostic		WC-34	
	WC-8, PP-11	WC-1	WP-7
	WS-7	WS-22	WC-14
	WS-22	MM-2	WC-17
	WS-25	PP-1	MM-2

is sufficiently homogeneous, a pulse will be received for each possible mode that can both be excited and propagate between the antennas. Since the group velocities of each type are different, the pulses will be received at different times. By measuring the time delay of the pulse along with its amplitude, phase, and spreading as a function of its frequency, the distance between the antennas, the antenna orientations, the angle of the path with respect to the magnetic field, etc., one can determine information about the dispersion relation and, hence, characteristics of the plasma such as density, composition, field strength, temperatures, drifts, etc.

The other area, including WP-4, WP-7, WP-15, WC-14, WC-17, WC-22, WS-22 and MM-2, consists of the transmission through the ionosphere of waves at VLF and lower frequencies. These are basically aimed at either generating waves (artificial whistlers for example) for geophysical measurements or exploring communication possibilities at lower frequencies. One can

transmit at either the PPEPL or the ground and receive at the other, and each has its advantages, although a ground to PPEPL transmission is normally the easiest. By measuring the received amplitude and phase as a function of frequency, relative PPEPL-ground site positioning, and the particular ionosphere which is present, one has a measure of the effect of the ionosphere on transmission and presumably the reason for it. This would, first, show how effective transmission can be with respect to communication and, second, it can be used as a geophysical diagnostic when it is effective.

In the boom to boom experiments the waves must have characteristic sizes smaller than the path distance; this limits the number of waves which can be investigated in a practical manner. The possibilities of orientation with respect to the background magnetic field for both the antennas themselves and the line joining them may be limited also. The size of the Shuttle vehicle will also be a severe handicap in this type of experiment (and to a lesser extent in all of the wave experiments) since it may act as a reflector for many of the waves. This will be worse than most noise sources in a manner analogous to "ghosts" on a TV screen.

The experiments involving transmission between the PPEPL and subsatellite are less restrictive in all of the above respects. This is, of course, due to the variability in the position of a subsatellite with respect to the PPEPL, both in terms of distance and orientation. However, a price must be paid for such flexibility and it appears in the difficulty of both achieving a desired position for the subsatellite and holding it for a length of time sufficient to make a measurement. For those cases where the exact position is not critical or even important, this is no problem; however, many experiments will require precise locations and for those it will be much more difficult.

The PPEPL-to-ground and ground-to-PPEPL experiments are generally of the types that have been previously carried out using natural sources, such as whistlers. These involve only electromagnetic waves at the ground end because of the lack of plasma, but electrostatic waves can still be involved in the ionosphere. The advantage of doing such experiments on the PPEPL will involve the reliability of the source, as well as the determination of its position.

One additional difficulty with transmission experiments will be the necessity for including the fact that the ionospheric-magnetospheric plasma appears very nonhomogeneous to a variety of waves. It will be very unlikely, at least for the boom-to-boom experiments and probably for those involving subsatellites as well, that many of the cases of interest can be carried out while neglecting the gradients in electron density, magnetic field strength, etc. When the curvatures of the ray paths are taken into account, these experiments become more

like the reflection experiments, wherein the gradients supply the mechanism for returning a signal. In fact, in some cases, it would be better to consider the boom to boom transmission experiments with specular reflection experiments, since there will probably be more similarities there. It may also be more applicable to include the wave-wave type of experiments for similar reasons.

Reflection experiments consist of transmitting and receiving on the PPEPL, possibly on the same antenna. The specular reflection properties provide a path for the wave which returns to the PPEPL. This method is applicable for both electrostatic and electromagnetic waves and is best exemplified by previous topside sounder experiments. The redbook experiments in this area (Table 4) basically require a sounder with most at RF and a few at VLF. The first is the only one that requires a sounder as a remote diagnostic to aid in another experiment. The rest are concerned with investigating the various plasma resonances and developing techniques for local diagnostics.

TABLE 4. SPECULAR REFLECTION EXPERIMENTS

Redbook Identification	Target	Wave	Interest
BP-2	Injections	RF	Diagnostic
WC-1	Ambient plasma	ES	Diagnostic
WC-4	Ambient plasma	5-20 kHz	Diagnostic
WC-10	Ambient plasma	RF, ES	Plasma resonances
WC-11	Ambient plasma	RF, ES	Plasma resonances
WC-16	Ambient plasma	RF, ES	Plasma resonances
WC-30	Ambient plasma	Lower hybrid	Diagnostic
WC-32	Ambient plasma		Plasma resonances
WS-22	Ambient plasma	ELF, VLF	Diagnostic
PP-20	Ambient plasma	RF	Plasma resonances

The inclusion of sounder type experiments on the PPEPL is best supported by considering their possible contributions to other experiments rather than the few suggestions in the area of plasma resonances. There are two reasons for this, the first being the remote sensing capability which can be important in all those experiments where the PPEPL will not pass through the region of particular interest. The second is the capability for making accurate and unequivocal measurements of the local electron density, which is of interest in itself and is also a help in calibrating other instruments. Another area may be in the measurement of electron temperature through the property of the resonances.

The so-called plasma resonances as have been observed with topside sounders are considered in several experiments and, since they have already been partially investigated, serve as a good example. Although the basic premise, pulse and listen, is quite similar to that for the electrostatic transmission experiments, the transmitter and receiver are located near each other rather than apart. The inhomogeneity of the plasma, a weakness in transmission experiments, provides the refraction which can return certain waves to their source. For electromagnetic waves, the signal is received very much as in the electrostatic transmission experiment. However, since the electrostatic waves are extremely sensitive to small changes in certain plasma properties, a large variation in dispersion exists over a small range of frequencies. This spreads the original pulse over such a large time scale that the response seems like a ringing rather than an echo. The phase and amplitude information can be converted into ray paths which then may be used to measure plasma properties.

The above process has been established for some resonances and will have a large effect upon the possibility of doing transmission experiments with these waves. Such waves would also be highly refracted and the dispersion of the pulse would be very large for any separation. An obvious possibility is to combine the ideas and use receivers at both a near transmitter point and also a remote location. This would provide two sets of propagation paths and would remove the effects of the antenna near-field for the latter case. Both of these features are highly desirable in terms of doing resonance experiments since the additional information does not compromise the simple sounder experiment in any manner.

In the case of backscatter, the situation is similar to that for specular reflection, differing only in that wave refraction is minimized and the return of the wave is due to plasma inhomogeneities rather than gradients. No backscatter experiments were suggested for the PPEPL but they should be considered, nevertheless. There are two general types:



1. Radar backscatter — scattering off well-defined ionosphere structures.
2. Incoherent backscatter — scattering off the random ionospheric inhomogeneities.

A radar backscatter experiment has been suggested for the proposed auroral Shuttle laboratory and can be incorporated in almost its present ground-based configuration since the equipment is portable. The purpose would be geophysical, to study the spectral characteristics of spread-F and/or auroral electron density irregularities. The frequency must be well above the plasma and electron cyclotron frequencies to insure as little refraction as possible. This implies frequencies above 50 MHz or so, but the actual frequency would be best determined by the size of the irregularity which is of particular interest. This involves the fact that the maximum scattering occurs at irregularities of a size similar to the wavelength. A variable frequency radar would best serve this purpose.

Incoherent backscatter is well known because of the several ground-based installations. The returning signal can be analyzed in terms of the power, a measure of the density, and the spectrum, which represents the particle velocity distribution. Although the waves are scattered by electrons, there are two different types of incoherent scatter. The first involves wavelengths larger than the Debye length of the plasma where the scattering takes place. In this case the spectrum is actually representative of the ion velocities, since this is the scale of their fluctuations. For shorter wavelengths, the spectrum of the electrons could be measured. This Thompson scattering at RF has not yet been achieved. Typical Debye lengths in the regions where the PPEPL is likely to be found could vary from a millimeter to possibly as large as a meter but would usually be few millimeters.

The obvious drawback to incoherent scatter from the PPEPL (and most likely the reason for the lack of suggestions in this area) is the large product of power and antenna size which is necessary in ground-based experiments. Typically, the antennas are large in order to achieve a highly directional signal and the power is large in order to insure a measurable amount of returning signal. However, the returning power is inversely proportional to the square of the range, and it is here that a tremendous advantage is available to the Shuttle. A reasonable range for ground-based installations would be 1000 km. For the Shuttle, the reflection need only occur far enough away from the vehicle to be in the ambient plasma, possibly as close as 100 meters. This is a ratio of  $10^4$  in range or a reduction of  $10^8$  in the possible power-antenna area product.

With the large amount of power available on a PPEPL, along with the practicality of developing reasonably large antennas, the possibility of a PPEPL scatter experiment should be considered for a variety of frequencies.

A PPEPL scatter experiment would have several advantages over ground-based installations. One would be the world-wide coverage and another would be the direct comparisons between its results and other measurements of the same parameters using different methods, sounders and probes for instance. Still another is the possibility of pointing in various directions to yield velocity distributions both along and across the background magnetic field, as well as bulk plasma motions. Ground-based experiments are basically limited to an upward direction which gives the velocity distribution with some particular angle to the magnetic field, namely the complement of the dip angle. Performing the actual Thompson scatter would provide a significant achievement, but the impracticality of doing this from the ground also applies to a PPEPL experiment and the advantages may not be sufficient to overcome this.

## B. Experiments Involving Nonlinear Effects

Both the advantages and disadvantages of doing experiments involving nonlinear effects can be attributed to the additional difficulties encountered compared to experiments involving only propagation. The more complex nature of the nonlinear experiments requires more measurements and demands a greater degree of knowledge concerning the ambient plasma. This difficulty has limited the degree of understanding in previous experiments, whether in the laboratory or in natural plasmas. The subject is thus open to a wider range of unsolved problems and, hence, there is more to be gained. The added difficulty in carrying out the experiments is then compensated to some degree by the enhanced possibility of new results.

There are two basic types of nonlinear effects, wave-wave interactions and wave-particle interactions. To understand either of these phenomena it is necessary to make measurements of several parameters simultaneously, both for the ambient plasma and the perturbations due to the waves and particles. Both will present difficulties in the design and interpretation of specific experiments. However, from the point of view of understanding the physics of the processes, the wave-wave interactions seem easier to implement since wave properties are simpler to measure than particle properties.

Most wave-wave experiments involve the simplest type of interactions, namely, the three-wave interaction. This results when three waves exist in

the plasma and have the following relationships between their frequencies  $\omega_1$ ,  $\omega_2$  and  $\omega_3$ , and the propagation vectors  $\vec{k}_1$ ,  $\vec{k}_2$  and  $\vec{k}_3$ :

$$\omega_1 = \omega_2 + \omega_3$$

$$\vec{k}_1 = \vec{k}_2 + \vec{k}_3 \quad .$$

Because of the large variations in the propagation vector as a function of frequency for each of the many wave modes which are possible in a plasma, these conditions are not difficult to meet. The experiment can either consist of inputting one wave and looking for the other two or, less frequently, inputting two waves and looking for another. Those redbook proposals with an interest in wave-wave interactions are listed in Table 5. Most of the interest in these areas is in the basic processes involved in wave-wave interactions with application to the ionospheric-magnetospheric plasma either in terms of understanding natural processes or using them as diagnostic tools.

A representative example would involve those proposed ideas concerned with the parametric instabilities, mentioned specifically in WC-13, MM-15, and possibly WC-23. The primary interest is concerned with their probable involvement in RF heating experiments, but most of the other ideas would involve similar procedures regardless of their goals. The study of the parametric instabilities would require the input of a relatively large amplitude wave at a frequency near a plasma resonance (RF). This would produce waves at a nearby frequency (RF), as well as one at a low frequency (VLF or lower). The amount of power necessary would depend upon the natural background noise in the appropriate frequency ranges and the conversion efficiency. In order to actually determine the processes involved in the nonlinear effect, it will be necessary to measure both the frequencies and the propagation vectors of each of the three waves. This is typical of the complications which enter into experiments involving nonlinear processes.

Very little has been mentioned in these proposals concerning the difficulties involved with such experiments. Observations of such interactions have been made with RF sounders, both with and without the addition of VLF receivers, so it is probable that interaction products can be generated and observed on the PPEPL. However, some of the previously observed interactions may be taking place in the sheath region surrounding the antenna (where the plasma is highly nonlinear) or even at the antenna sheath interface. Since it is desirable to produce and observe wave-wave interaction in the ambient plasma, a good deal of care will have to be taken to determine and, if necessary, control the region in which the effect takes place. By measuring the propagation vectors it is possible to determine the source of the products.

TABLE 5. WAVE-WAVE INTERACTION EXPERIMENTS

Redbook Identification	Waves	Interest
BP-24	ES at $\omega_p \rightarrow$ EM at $\omega_p$ , ES at $2\omega_p$	Astrophysics
WP-3	ES electron, ion cyclotron harmonic	Nonlinear
WP-13		Nonlinear
WC-2	2 RF $\rightarrow$ sum	Nonlinear
WC-3	Three wave	Nonlinear
WC-13	HF $\rightarrow$ VLF	Parametric instabilities
WC-20	Langmuir, ion acoustic	Nonlinear
WC-23	HF, VLF	Nonlinear
WS-28	100 kHz-3GHz	Diagnostic
MM-5	Near plasma resonance	Parametric instabilities
PD-20	Diffuse plasma resonance	Diagnostic

Even if the interaction occurs or can be made to occur in a desirable volume of the ambient plasma, a number of difficulties will be involved in carrying out the experiment. These are concerned with both the placement of the transmitter and receivers and their associated antennas, and the choice of a transmitting frequency. Unless information is available concerning the ambient plasma so that decisions can be made as to the best input frequency and the location for receiving, the experiments would be randomly effective. With the large number of possible modes available both in transmitting and in interaction products, it would be exceedingly difficult to identify the particular process involved without very precise measurements.

There is a wide variety of suggestions for experiments involving wave-particle interactions. Stated simply, these consist of either modifying the

ambient plasma by the introduction of particles in order to stimulate a growing wave or to input a wave which interacts to alter the plasma (usually the electron velocity distribution) in a semipermanent (nonoscillatory) manner. The various redbook suggestions are given in Table 6. Again, it is assumed that the source is on the PPEPL, unless otherwise indicated.

The basic ways particles are used for altering the plasma to produce waves are by beams and injections (releases). In addition, the turbulent wake is considered as a possible source in three WS area proposals. High power transmitters on both the PPEPL and the ground have been suggested as sources for waves which could alter the plasma. In some cases the purpose is to study the basic processes of nonlinear wave-particle interactions, and in others it is to study the ionosphere-magnetosphere through the use of the interactions as a diagnostic. The rest are not concerned primarily with the wave-particle interaction but have other interests, such as wave irradiation. Those which can be considered primarily wave-particle are categorized in Table 7. A majority of the experimental interest is geophysical in nature, with most of the interest in basic wave-particle interactions concerned with beams.

The beam and particle injection experiments are generally of greater interest to those concerned with particles than to those concerned with waves. The study of this subject is then more appropriate for other groups. However, waves may play a very prominent role in the actual experiments since they offer the opportunity for making remote measurements. This is true in a passive sense, through the observation of waves originating from the effects of the beam or injection; and also in the active sense, through the use of RF sounding and scatter techniques. Even so, there will be problems similar to those discussed for wave-wave experiments. If the beam or injection originates on the PPEPL, it will not necessarily be possible to receive any resultant emissions at the PPEPL or reach it with active techniques. This is a more severe handicap in the case of injections since the anticipated effects may not take place for a substantial period of time, at which time the PPEPL would have moved a large distance away. Injection by rockets may be a more practical method, and wave techniques could be used in the vicinity of the affected area and direct measurements made if the PPEPL could pass through the disturbed region. Because of the large amount of coordination this would involve, such solutions are not perfect, however. Obviously further investigation will be necessary to better define the practical possibilities for beams and particle injection experiments.

Those proposals involving the injection of waves to produce changes in the ambient plasma are generally of two types, heating and cyclotron instabilities. Some of the proposals, MM-1, MM-5, and MM-14, involve heating from

TABLE 6. EXPERIMENTS INVOLVING WAVE-PARTICLE INTERACTIONS

Redbook Identification	Source	Wave	Particle	Interest
BP-2	Various injections	VLF	Various	Magnetosphere
BP-7	Beam	ES, EM	Electrons	Beam characteristics
BP-9	Beam	ULF, ELF	Protons	Beam stability
BP-14	Beam	Plasma waves	Electrons, ions	Beam stability
BP-19	Beam	ES, EM	Electrons	Magnetospheric
BP-21	Natural	ES, EM	Electrons, protons	Diagnostic
BP-22	Beam	ES, EM	Various	Beam stability
BP-23	Beam	1Hz-20MHz	Various	Beam turbulence
BP-24	Beam	ES, EM	Electrons, protons	Astrophysical
WP-1	Transmitter	Whistler	Electrons	Cyclotron instability
WP-2	Natural		Various	Diagnostic
WP-3	Transmitter	RF	Electrons, ions	Wave-particle
WP-5	Natural			Diagnostic
WP-8	Natural	ELF-VLF		Wave-particle
WP-9	Transmitter	Various	Various	Wave-particle
WP-10	Modulated beam	Whistler	Electrons, ions	Irradiation
WP-11	Helical beam	VLF	Electrons	Irradiation
WP-12	Transmitter	VLF	Electrons	Cyclotron instability
WP-13, MM-11	Transmitter	EM		Nonlinear
WP-14	Transmitter			Wave-particle
WP-15	Rocket explosive charge	EM		Diagnostic
WP-18	Helical beam	0.1-20Hz	Ions	Irradiation
WC-2	Transmitter	RF		Nonlinear
WS-1	Wake			Turbulence
WS-13	Wake	< few kHz		Turbulence
WS-14	Wake	ES		Turbulence

TABLE 6. (Concluded)

Redbook Identification	Source	Wave	Particle	Interest
MM-1	Ground transmitter	RF		Heating
MM-3	Transmitter	Magnetic		Magnetosphere
MM-4	Beam, injection			Magnetosphere
MM-7	Release	ES	Barium	Diagnostic
MM-10	Release	VLF	Ions	Diagnostic
MM-12	Transmitter	VLF	Electrons	Diagnostic
MM-14	Ground transmitter	VLF	Electrons	Heating
MM-16	Transmitter	Alfven	Ions	Heating
MM-20	Transmitter	RF	Electrons	Heating

the ground. For these cases the PPEPL acts as a passive observation platform and the appropriate considerations are similar to those for particle injection by rockets. Two others, MM-16 and MM-20, suggest doing the heating from the PPEPL with Alfven waves and RF waves, respectively. The latter case is quite similar to parametric instability experiments, but would involve more power. The motion of the PPEPL presents severe problems with local heating, since it will be very difficult to interact in a determinable manner with an identifiable and stationary volume of plasma for any length of time. There is also a problem in observing the region even if it can be heated. The best opportunity would seem to involve heating a region ahead along the orbit so that the PPEPL would later pass through it. This would involve a detailed knowledge of the ionosphere and could only work under a fortunate set of ionospheric conditions, at least for RF heating. If sufficient power were available, the heating might be done quickly enough to overcome some of these problems, but, again, there are obvious questions to be answered before such experiments could be considered practical.

The precipitation of particles from cyclotron instabilities triggered by large amplitude VLF waves is mentioned in both WP-1 and WP-12. Again, there is a problem in logistics, namely that of trying to inject the wave and measure the results from the same vehicle. Rockets or subsatellites may provide an answer, although this would require an extensive amount of coordination. All of the wave injection experiments may also suffer from an inability to produce waves of sufficient amplitude. The possible amplitude seems to decrease with decreasing frequency, but it is by no means certain that practical amplitudes can be achieved even at RF.

TABLE 7. WAVE-PARTICLE INTERACTION EXPERIMENTS

	Beam	Injection	Ground Transmitter	PPEPL Transmitter
Nonlinear Theory	BP-7		MM-1	WP-9
	BP-14		MM-14	WP-13, MM-11
	BP-19			WP-14
	BP-22			WC-2
	BP-23			
	BP-24			
	WP-3			
Diagnostic	BP-2	BP-2	MM-1	WP-1
	BP-7	WP-15	MM-5	WP-9
	BP-9	MM-4	MM-14	WP-12
	BP-14	MM-5		WP-14
	BP-19	MM-7		MM-3
		MM-10		MM-12
				MM-16
				MM-20

### C. Wave Sources

Except for those cases where either natural waves are to be observed or waves are to be excited by sources on the ground or on other vehicles, it will be necessary to stimulate the desired waves by some mechanism on the PPEPL.



The two possibilities are field sources (antennas) and particle sources (beams and releases). The determination of which type of source to use may arise out of practical considerations or may come from an intrinsic interest in a particular system. In this latter instance the system is predetermined. This also is true in some of the former cases where it has already been established that particular sources are quite satisfactory. In many cases, however, it has yet to be determined which, if any, type of source can produce a particular wave with the desired amplitude.

Table 8 contains a list of those redbook proposals which require a PPEPL wave source. In many of these, the wave source is actually not stated and, in others, a different source than that requested may be superior. Several of the proposals are concerned directly with the problems of wave sources either because of an intrinsic interest in them or because of an appreciation for the difficulties in stimulating certain waves. Those proposals which have a primary interest in a wave source are listed in Table 9.

The interest in beams as sources is primarily concerned with low frequencies where normal antennas may not be practical. Most requests for an injection have a geophysical interest behind them and the waves are primarily for diagnostic purposes. Proposals related to antenna behavior cover the entire range of frequencies but are most numerous at lower frequencies. The interest in probes is limited to the quadripolar type, although this need not be a limitation in the future.

The greatest hindrance to experiments with wave sources at this point is the lack of information which can be used to make suitable judgments. Antennas, releases, and beams immersed in plasmas are very complicated systems and do not seem easily approached in terms of simplified theories. The amount of information pertaining to the antenna plasma interaction in the case of RF sounders is a striking example of this lack, even though such experiments have been in operation for a decade.

On the other hand, some of the experiments would be so simple that the easiest approach might be to try them. This is most obvious in the cases where the possibility of radiating certain waves is of interest. For such examples, the process of trying to receive a radiated signal, whether on the ground, in a subsatellite, or on a PPEPL boom, along with a PPEPL transmitter and antenna (or beam) make up the entire experiment. There does seem to be a large amount of concern about operating transmitters at low frequencies and high voltages, but, while such concern at this point is creditable, there does not seem to be a reason for restricting low frequency transmitters to low voltages. Since this area could be investigated with rocket or satellite experiments (and theoretically) before the PPEPL flights, such questions should be resolved as soon as possible.

TABLE 8. EXPERIMENTS INVOLVING PPEPL WAVE SOURCES

Redbook Identification	Type	Wave	Interest
BP-2	Beam, release	VLF	Magnetosphere
BP-7	Electron beam	ES, EM	Beam characteristics
BP-9	Proton beam	ULF, ELF	Beam stability
B-14	Electron and ion beams	Plasma waves	Beam stability
BP-19	Electron beam	ES, EM	Magnetosphere
BP-22	Various beams	ES, EM	Beam stability
BP-23	Various beams	1Hz-20MHz	Beam turbulence
BP-24	Electron and proton beams	ES, EM	Astrophysical
WP-1	Dipole or loop	Whistlers	Cyclotron instability
WP-3	Antenna	RF	Nonlinear
WP-4	Antenna	VLF	Irradiation
WP-7	Antenna	LF	Diagnostic
WP-9	Antenna	VLF-HF	Nonlinear
WP-10	Modulated electron ion beam	ELF-VLF	Irradiation
WP-11	Helical electron beam	VLF	Irradiation
WP-12	Dipole or loop	VLF	Cyclotron instability
WP-13	Antenna	EM	Nonlinear
WP-14	Large antenna		Nonlinear
WP-15	Helical proton beam	Hydromagnetic	Irradiation
WC-1	Antenna	RF	Diagnostic
WC-2	Antenna	RF	Nonlinear
WC-3	High power	< 3GHz	Nonlinear
WC-4	Antenna	5-20kHz	Diagnostic
WC-6	Pulsed magnet	< 1 Hz	Diagnostic
WC-7, PP-10	Antenna	VLF-HF	Long delay echoes
WC-8, PP-11	Probe, antenna	RF	Diagnostic
WC-9	Antenna	RF	Dispersion relations
WC-10	Dipoles, others	RF	Resonances
WC-11	Dipoles	RF	Resonances
WC-13	Antenna	HF	Nonlinear
WC-14	Antenna	ELF	Diagnostic

TABLE 8. (Continued)

Redbook Identification	Type	Wave	Interest
WC-15	Various antennas Electron and ion beams	Sub LF	Communications
WC-16	Antenna	RF	Resonances
WC-17	Superconducting magnet	0-20MHz	Propagation
WC-18	Antenna	ES	Propagation
WC-19	Antenna	0-20MHz	Propagation
WC-20, PP-8	Antenna	Various	Propagation, nonlinear
WC-24	Electric, magnetic, particle		Dispersion relations
WC-30	Quadrupole probes	Near LHR	Diagnostic
WC-34	Antenna	EM	Nonlinear
WC-35	Dipole, quadrupole probe	VLF	Diagnostic
WS-1	PPEPL wake		Nonlinear
WS-4	Antenna	RF	Antenna effects
WS-13	PPEPL wake	< few kHz	Nonlinear
WS-14	Antenna		Antenna impedance
WS-18	Antenna	Low phase velocity	
WS-22	Antenna	ELF-VLF	LHR sounder
WS-25	Antenna	ES	Diagnostic
WS-28	Antenna	100 kHz-3GHz	Nonlinear
MM-2	Antenna	VLF	Diagnostic
MM-4	Beams, releases		Magnetosphere
MM-5	Antenna	Near plasma resonances	Nonlinear
MM-7	Barium release	ES	Magnetospheric
MM-10	Ion release	VLF	Magnetospheric
MM-11	Antenna	EM	Nonlinear
MM-12	Antenna	VLF	Nonlinear
MM-16	Magnetic loop	Alfvén	Nonlinear
MM-20	Antenna	RF	Nonlinear

TABLE 8. (Concluded)

Redbook Identification	Type	Wave	Interest
PP-1	Antenna	RF	Propagation
PD-11	Quadripole probe	Various resonances	Diagnostic
PD-17	Antenna		
PD-20	Antenna	100 kHz-5MHz	Diagnostic
PD-21	Quadripole probe	100 kHz-20MHz	Diagnostic

TABLE 9. WAVE SOURCE PROPOSALS

Beam	Injection	Antenna	Probe
WP-10	WC-15	WC-6	WC-35
WP-11		WC-15	WS-1
WP-18		WC-35	PD-11
WC-15		WS-4	PD-21
		WS-14	
		WS-18	

### III. CONCLUSIONS AND RECOMMENDATIONS

At the present time there are two definite statements that can be made concerning the possibility of doing wave experiments on a vehicle such as the PPEPL. First, the large response, as represented by the number of experiments that have been suggested, is indicative of a much interest. Second, in very few cases have proposals mentioned the difficulties that will be involved in carrying out the experiments and, more importantly, there are only a few proposed experiments which capitalize on the unique aspects of the PPEPL.

It is too early in the development stage of the PPEPL to consider individual experiments in detail. However, some general statements can be made in several of the experimental areas concerning the advantages and disadvantages of the PPEPL in carrying out the experiment and, where applicable, individual supporting proposals. Some of the advantages are common to any space vehicle, namely, those involving the plasma, such as the lack of boundaries and the size and homogeneity of the working volume. There are also common disadvantages such as the electromagnetic interference, the undesirable perturbation to the plasma, the motion of the vehicle through the plasma, and the lack of control over the plasma. The size of the PPEPL can be a peculiar disadvantage while the common disadvantages of spacecraft may also be magnified in the PPEPL case. The PPEPL adds the advantages of its size, the weight it can carry, the available power, the data handling, the presence of many measuring instruments along with their alterability, the presence of man, and the possible use of subsatellites. These advantages and disadvantages are discussed more specifically in the following sections.

## A. Advantages of PPEPL

1. Plasma. All of those wave experiments whose objectives are to understand geophysical processes share in the ability of the PPEPL, or any other spacecraft, to make in situ measurements. As an example, experiments MM-1 and MM-5, the RF heating experiments, specifically state the advisability of making such measurements. Such considerations are not stated specifically in most other proposals, but they can be inferred in a wide range of cases.

The advantages in terms of using the ionospheric-magnetospheric plasma as a laboratory for basic plasma physics are not so clear cut. Only three experiments mentioned the partial lack of boundaries, BP-19, WC-3, and PD-11. Some advantage for the ionospheric-magnetospheric plasma may also be inferred from several of the redbook proposals. However, there are areas where the natural plasma is well suited for doing basic physics and in some cases, whistlers for example, the experiments are exceedingly difficult to do in a laboratory.

2. PPEPL Size and Weight Capability. This is an area where no reference is made directly in any proposal as to the advantages of the large size and weight-carrying capability, but such an advantage is implied in a large number of experiments. The list would include at least WP-4, WP-14, WC-2, WC-6, WC-8, WC-10, WC-15, WC-18, WC-19, WC-20, WC-35, WS-4, WS-7, WS-22, PP-8, PP-11, and PD-17. All of the boom to boom transmission experiments

use the size to advantage, as do the obvious cases where very large antenna structure may be needed. The electron and ion collection capability resulting from the large surface area may be helpful in beam experiments. It is more difficult to estimate the advantages when considering the weight, but it is also obvious that this will at least remove a design restriction for many experiments and some may necessarily be sufficiently heavy to preclude their consideration on normal spacecraft, very large antennas for instance.

3. PPEPL Power. Here again, although few suggestions include reference to the PPEPL as a necessity in terms of its available power, many experiments request high power. In cases involving waves, these are in the form of high power transmitters. Included in these would be WP-1, WP-3, WP-9, WP-12, WC-3, WC-6, WC-14, MM-11, MM-20, and PP-1. The power is, in general, necessary either for the production of nonlinear effects or to provide sufficient radiated energy. The prospect of doing any backscatter experiments would also depend upon this advantage, as well as the considerations of size and weight. A more subtle consideration is the practicality of operating several high power experiments simultaneously, thereby providing coordinated measurements in areas necessarily avoided on conventional satellites.

4. Measurement Capabilities. One of the desired features in all experiments is the ability to measure a variety of appropriate parameters; the PPEPL could provide a significant improvement in this area. Comparison of experimental values is mentioned in BP-2, BP-7, BP-14, BP-24, WS-22, and PD-1. In addition, most of the suggested experiments involve the use of more than one instrument. The PPEPL advantage over a smaller spacecraft is not limited in this area to merely numbers, however. A significant advantage would involve the ability to operate instruments simultaneously by placing them far enough apart to eliminate the mutual interference which sometimes occurs. This situation is extremely important for all nonlinear type experiments.

5. Telemetry and Data Handling. This area has great significance to wave experiments since most of them involve large data bandwidths which are difficult to telemeter on a regular basis. Three experiments actually mention the bandwidth requirements — WC-1, PP-1, and PD-11 — and many others will have similar needs. The ability to either record the data directly in the PPEPL or even do the pertinent analysis on board could eliminate any necessity for wide-band telemetry.

6. Role of Man. Contributions to the experiment by the presence of an experimenter in an active role was mentioned in only three wave proposals — MM-4, PD-19, and PD-20. There is even some thought that man's presence

should be considered in the disadvantage column. There are two ways in which a man might be advantageous, as a caretaker and controller of the experiment.

The role of the caretaker might involve such areas as the deployment of equipment, particularly such items as antennas, when simpler than by electromechanical means; changing or repairing equipment, either inside or outside; and monitoring experiments. Any advantages obtained by allowing outside activities (EVA) would have to be balanced against the associated difficulties involving evacuation and airlocks. In many cases an astronaut can more readily accomplish outside mechanical tasks than a device; EVA might be considered. The repair of internal equipment is probably not an important feature because of the short mission times. Monitoring experiments would be quite simple and could be helpful in terms of discovering faults in operation or making simple adjustments, such as in range or gain.

Actual active experimental participation by an onboard passenger is a possibility which can best be assessed by the experimenter. It would seem advisable, however, that, since the capability for such participation will presumably be available, the opportunity should be exploited to its greatest extent.

7. Subsatellites. Of all the unique features of the PPEPL which have been considered, the use of a subsatellite as an adjunct is mentioned most often. Over half of the proposed experiments involving waves — BP-2, BP-7, BP-14, BP-19, BP-22, BP-23, BP-24, WP-1, WP-2, WP-3, WP-4, WP-8, WP-10, WC-2, WC-5, WC-7, WC-9, WC-10, WC-11, WC-13, WC-17, WC-18, WC-19, WC-20, WC-23, WC-24, WC-34, WC-35, WS-1, WS-4, WS-28, MM-2, MM-11, PP-1, PP-10, and PD-17 — mention specifically the desirability of a subsatellite. The main reason for this popularity is the flexibility that the subsatellite would provide in terms of its arbitrary positioning with respect to the PPEPL or an effect caused by the PPEPL. In some cases this is a matter of getting an instrument away from the PPEPL either to avoid the plasma perturbation or to provide a long baseline. In others it is a problem of getting to the only place where it is actually possible to make an observation.

## B. Disadvantages of PPEPL

1. Plasma Perturbation. To those persons interested in wakes and sheaths per se, the perturbation in the plasma due to the vehicle and its motion through the plasma is an item to be studied. To most others, however, the PPEPL and Shuttle would be considered a boundary and its wake and sheath an

inhomogeneity. Fortunately, most wave experiments do not involve a large and direct effect due to this problem, but it is still mentioned in BP-24, WP-1, WP-3, WP-7, WC-1, WC-28, WS-1, and WS-14. The last two cases belong in the category of those interested in wakes and sheaths. Most of the others express a desire to place the antennas away from the PPEPL-Shuttle in order to be outside the large perturbation.

Despite the relatively small effect of the perturbation on wave experiments, there are areas where it is very important. One of these involves the sheath around an antenna, no matter where it is positioned, since it affects the amount of power which can be radiated as a given wave. Another involves the possibility of a variety of nonlinear effects occurring in the sheath-antenna region.

2. Electromagnetic Noise. The presence of electromagnetic noise is always a problem in wave experiments but is one that can be alleviated. It is mentioned in one proposed experiment, PD-11, but is of importance to all. One source of noise has been discussed previously, namely reflections off the Shuttle. Another source is the natural noise in the plasma. This must be lived with and is, in fact, of use to some. The other source originates from the PPEPL-Shuttle itself, and can be minimized if considered in the design stage.

3. Vehicle Motion. The motion of the spacecraft through the plasma creates two other problems besides the perturbation which it causes. The first of these involves the problem of a rest frame for the wave propagation. However, this can be accounted for provided the wave is given a correct Doppler shift. In some experiments, this even provides a source of information. Waves whose group velocities are smaller than the vehicle velocity with respect to the plasma will be a possible problem since they will not be able to keep up with the PPEPL. In transmission experiments these will only be seen if the transmitter is ahead of the receiver, either on booms or on a subsatellite.

The second consideration is the indirect effect of a plasma whose properties change in time. This makes it very difficult to spend an appreciable time in any particular plasma region. Hence, some experiments will have a very short time for accomplishment if they are to be completed in a given plasma. This problem of time is not mentioned in any of the suggested experiments. Furthermore, a few experiments may become completely impractical from this standpoint, the RF heating from the PPEPL, for example.



4. Lack of Plasma Control. This problem will not be severe as long as those who propose experiments are aware of what sorts of plasma they can expect to encounter on a particular mission. The fact that an orbit will cover a range of fairly predictable conditions and that the missions will involve a large number of orbits means that the desired plasmas will be available within a known set of parameteric limits.

There are, of course, a number of other considerations to be made when determining the advantages and disadvantages. The outlook here has been to consider only the variety of experiments which may be done and not to compare them either with each other or in absolute terms. Hence, such eventual considerations as cost have not been discussed. There are, however, some indications of the way to proceed in the further consideration of wave experiments in the PPEPL, and this is discussed next.

## C. Future Possibilities

The reaction to the request for experimental suggestions, as exemplified in the redbook, provides a stimulus for future investigations. However, this is shown mainly in the amount of interest expressed rather than in the content of the suggested wave experiments. This is not surprising since the program is at such an early, nebulous stage. The questions that are important are whether further study and discussion will bring about a refinement in those areas of present investigation in order to take better advantage of the PPEPL possibilities, and whether new areas of investigation will be stimulated. In the latter case, such ideas will often be in the form of offshoots from other experiments either as observations or as ideas. This type of possibility makes imperative a large amount of flexibility in any future plans.

A desire to allow for future changes should not be construed as a reason for less planning, however. Plans should be based on instrumentation which would accommodate whole areas of experimentation rather than on instrumenting very specific experiments to yield particular results. There are a number of areas which need to be investigated thoroughly before it is necessary to be concerned with a specific proposal. This implies a systematic approach to the whole rather than an emphasis on achieving a few narrow goals.

One of the most important and, fortunately, most obvious areas where a systematic approach would be beneficial is in the area of wave sources, either in the form of antennas or particles. Presumably, most of the research in the area of waves would involve a source on the PPEPL and, hence, it is

vital to understand the processes which will not only produce the desired waves but which will also produce other effects which may be important. It would seem then that the first area of interest would be a study of antennas and particle wave sources in plasmas.

The development of wave sources as an initial endeavor is logical from several standpoints. First, some of the work can be done before there are Shuttle flights, probably on rockets. Second, much of the study could be performed on early PPEPL missions where the emphasis will probably be on systems and equipment anyway. Third, many proposals are predicated on the availability of a particular wave and it does not seem reasonable to find out how well this can be achieved, if at all, after an entire wave experiment has been planned. And last, it would be hoped that this would be a source of new ideas based upon some of the nonpredictable effects that are almost certain to be seen.

Once it becomes clear what sort of waves can be generated and also what other effects will accompany them, experiments involving the fundamentals of the waves themselves can be considered. The various types of propagation experiments will be the simplest and should be attempted first. The other types, such as those involving nonlinear effects, could then be investigated. Actually, many of these will undoubtedly have been observed when either investigations of the sources or wave propagation experiments are being pursued. In this manner, various areas involving waves would always be investigated as byproducts of experiments involving one particular area. The general order for placing the experimental emphasis provides a basis for each subsequent stage.

One consideration that has obvious merit even at this early point is the inclusion of a subsatellite capability on the PPEPL. Such a possibility greatly enhances the outlook for almost all of the experiments involving waves. Some are simply improved, many will go from marginal to probable in the expected success, and some are not practical in any other way. The greatest benefit would come from a subsatellite that is maneuverable and instrumented in a sophisticated manner, but even a passive subsatellite providing a platform for an experimental instrument along with a power source and some telemetry capability would provide a large amount of enhancement.

The diagnostic capability of wave experiments can contribute to other experimental areas. This includes the standard type of RF sounder which will measure local electron density and, possibly, temperature and can make remote measurements as well. It may be possible to operate a similar instrument at lower frequencies to provide some ion information. The incoherent

backscatter could also provide local diagnostic data. The radar backscatter is one of the few possible remote diagnostics and could be of use in many of the particle experiments which cannot be done in the immediate vicinity of the PPEPL.

Waves have not yet been planned as a diagnostic to study vehicle wakes, nor is it obvious that particle detectors of one form or another will provide very reliable measurements because of the gross inhomogeneity and anisotropy of this region. It would seem advisable to develop a wave experiment, possibly a transmission experiment, for wake studies. The small scale size for the wake is a problem with wave experiments, but an experiment utilizing high frequencies might be designed. An extreme case using laser backscatter, WS-26, has in fact been suggested and, while such a procedure is not considered practical at this point, it should be kept in mind.

There are several problem areas where some planning at this stage would be advantageous; one involves EM noise. Since it is likely that experiments involving frequencies across the entire spectrum from dc to visible light will be included, any frequency used in the onboard equipment is a potential source of trouble. The easiest way to alleviate this is to provide good shielding in all those cases where ac is necessary and to provide dc when possible. The use of dc in power supplies would be desirable, even if this were made a temporary system for use when a normal ac system may cause trouble. If it is impractical to provide complete EM cleanliness, the contamination should be documented.

Problems with contamination of the particle type are not usually important for wave experiments since they tend to sample the ambient plasma anyway. It could be a problem if antennas were in the large wake of the Shuttle, but presumably this will be avoided. Potentials on the vehicle may be of concern in wave experiments, as well as in particle experiments, since it may be desirable to bias antennas at times in order to change their characteristics.

The greatest problem is going to be the one of logistics for individual experiments, for each mission, and for the overall PPEPL. For an individual experiment, the motion of the PPEPL through the changing plasma will perhaps determine when the experiment is possible and how much time will be available for it. Such considerations can affect the choice of orbit and even whether an experiment can be done at all. This supposedly can be left to the experimenter himself, but, in those cases where many different types of measurement are required for a simple experiment, a large degree of cooperation may be necessary between experimenters. This phase of the research effort cannot be stressed too much.

Planning any particular mission, whether of 7 days or longer can be made difficult unless a sufficient number of options exist. There is always a possibility that a certain piece of equipment will not function properly (assuming redundancy will not be a requirement) and there is always a probability that conditions will not be right for certain experiments, at least not on a schedule. The occurrence of interesting, unpredictable natural phenomena may also create an interest in changing the experimental schedule. The occurrence of a magnetic storm, for instance, might upset planned experiments but could also be of interest in itself. Hence, the planning for any particular mission cannot be overly specific. This also has a ramification on the choice of crew, pointing toward having at least some occupants who are knowledgeable in more than one scientific area.

Overall planning will be even more difficult. It has already been suggested that the initial emphasis of the wave experiments be on the problems of sources; this suggests a cooperative effort rather than individual experiments. At some point questions are going to have to be answered, such as whose experiment to use when there is more than one proposed, who to send on the missions, and what to do with the data. In general, any mission will be expensive and it will be quite important to ensure the best use of such a facility as the PPEPL.

## D. Equipment and Instrumentation

The basic units of equipment and instrumentation necessary for doing active wave experiments include antennas, receivers, transmitters, and a few peripheral devices. Of these, only in the area of antennas (particle or field) is much extensive development necessary. The other areas are already sufficiently developed to meet practically all of the requirements that have been presented at this point.

In the area of antennas, it is important to consider the various possibilities at an early stage because the size and placement of the devices will affect the overall laboratory design, at least externally. The use of beams as antennas may prove to be the only possible method of radiating at lower frequencies, but at this point there is an insufficient amount of knowledge available to formulate any conclusions. The beam antenna area needs extensive investigation and would best be approached from the particle point of view.

There is a variety of field-type antennas that could be employed, although their properties in a plasma are not completely established. At very high frequencies, well above the local plasma or cyclotron frequencies (above

say 25 MHz), the plasma has little effect on antenna characteristics. For experiments in this frequency range, namely, coherent and incoherent backscatter, normal free space considerations are ample. Possible antennas are thin dipoles, log-periodic arrays, YAGIs, and parabolic dishes. These are mentioned in order of increasing directivity, since the backscatter experiments would be enhanced by smaller beam widths. The size of the various types of antennas are related to wavelength as approximately:

Dipole	$\frac{1}{2}$ wavelength long
Log-periodic	2 wavelengths across
YAGI	2 wavelengths across
Parabolic dish	5 wavelengths minimum diameter

Hence there is a certain amount of trade-off between size and directivity. The wavelengths which might be involved in backscatter radar range from approximately 15 meters at 20 MHz to 5 millimeters at 60 GHz. A 5-meter diameter dish could be highly effective for wavelengths less than 1 meter or for frequencies above 300 MHz. They can be made with a wide bandwidth by altering the center element; compactly folded forms, such as those used in the Apollo program and communications satellites, have been extensively developed. For lower frequencies it may be necessary to sacrifice some directivity in order to keep the size within reasonable limits. The YAGI is very directional but limited in bandwidth while the opposite is true for a log-periodic antenna. When directionality is not an important consideration, dipoles may be used. In all cases it would be important that the antennas be steerable.

At frequencies below about 25 MHz, antennas interact with the plasma to a widely varying degree. A variety of electric and magnetic antennas, including dipoles, loops, and ferrite cores, have been used for purposes of receiving. Only dipoles have been employed for transmitting purposes and then only down to about 100 kHz (with the exception of impedance type experiments, such as the quadripole probe). At lower frequencies it is difficult to construct half-wave dipoles or their equivalent in a plasma since the wavelengths become prohibitively long. Even the fact that the wavelengths in the plasma are shorter will not adequately compensate for this, but there do exist possible regions where the wavelengths of electrostatic waves will be sufficiently short to be effectively excited. Loops are poor radiators under normal circumstances but may have the advantage of not putting much of the energy into electrostatic modes, a condition which probably exists for dipoles. Array type antennas may

offer some advantages over dipoles if the directional characteristics are important; the possibility of their inclusion needs further study. The only practical possibility for a very large antenna would be a monopole consisting of an arbitrarily long wire with a high drag device (balloon) at one end. The drag differential would stretch the wire out behind the PPEPL to form a relatively straight conducting element, but the orientation is limited. An alternative may be to use maneuverable subsatellites to deploy a long dipole.

The positioning and orientation of whatever antenna systems are eventually used will be quite important in a variety of experiments. A variable orientation for any system would increase the amount of possible time for doing a particular experiment to an extent sufficient to make it a necessity. Since the entire PPEPL-Shuttle spacecraft will probably not be maneuverable over widely varying orientations in a short time, the antennas themselves must be quickly adjustable to a variety of positions. Positioning the antennas at the ends of booms is also highly desirable for two reasons: The first concerns being removed from the large Shuttle perturbations (plasma and EM noise); the second is related to the shadowing effect of the Shuttle. Neither of these may be an important consideration for cases where the antennas are either large or highly directional. The presently planned system of using the long dipole on the pallet and a shorter dipole on a boom for transmission experiments may not be very suitable, since it is better if the antennas are identical.

Receivers should offer few problems as long as a minimum amount of care is exercised. A variety, operating over a wide range of frequencies, have already been flown on spacecraft. The experience on the ground is even more varied and can be utilized almost directly. The only sources of difficulty may lie in the remote location of the receiving antenna and its large variability in input impedance. The noise problem which will arise if signals must travel a long distance from receiving antenna to receiver can be overcome to a large extent by placing the preamplifiers at the antenna terminals. These might be tunable or fixed frequency, narrow band devices or wide bandwidth devices, the characteristics to be determined more precisely by the specific experiment. Since these are small (in the few cubic centimeters and fraction of a kilograms range), it should be possible to switch between two or more mounted at the antenna if a variety of stringent requirements are to be met on a single mission. The receiver itself can most easily be made versatile by the use of plug-in units, a widely used concept at present. At least two independent receivers will eventually be necessary for many experiments, particularly those involving wave-wave interactions, although one might be on a subsatellite.

Transmitters are not much of a problem in principle, although there will be some natural difficulties associated with handling the high voltages, possibly

20 kV, which might prove desirable. The transmitters can be divided into two types, low frequency and high frequency. The low frequency regime offers the possibility of being completely versatile if the input is computer formed. At the present levels of technology one could program any imaginable wave form up to a frequency of 20 kHz with a better than 1 percent resolution. This is done simply by controlling the transmitter input with a signal from a digital to analog converter. If a square wave is adequate (and these can be filtered), this can extend up into the megahertz range. Furthermore, programmable voltage regulators that are in current use could operate as the final output up to a few kilovolts and few kilohertz. In its simplest form, then, the transmitter might consist of a high voltage source, a voltage regulator, and a digital-to-analog converter.

At the higher frequencies, a multitude of examples of operating transmitters having a wide range of characteristics are being used. Wide band, stable transmitters in the RF and VHF ranges can be designed with pulse shaping options and high output voltages. In both frequency regimes, however, it will be necessary to protect the system so that it will operate safely into any load, from an open circuit to a short circuit, and from purely resistive to purely reactive.

The choice of the other equipment that can be used in conjunction with the receiver is somewhat up to the particular experimenter. However, some devices will prove generally useful, including counters, analog to digital converters, and oscilloscopes. One of the latter, at least, should be of the memory type. It is assumed that much of the computer capability will also be permanently available for such purposes as Fourier analyzing or manufacturing of pulse shapes for a transmitter.

In addition to the equipment directly involved with making the wave measurements themselves, a number of other experimental measurements will be useful and, in some cases, necessary. Most of these should be satisfied by those instruments which will probably be a part of the standard payload — probes, magnetometers, etc. Experiments involving wave-particle interactions will require measurements of velocity distributions of electrons or ions or both, and this implies the presence of spectrum analyzers in the proper energy ranges, as well as in the correct physical location, i.e., in booms or subsatellites. It will be most important that any instruments which might be used in conjunction with experiments in other areas be capable of handling a variety of situations.

## E. Summary

In summary, the following statements can be made about wave experiments on the PPEPL:

1. There is much interest in doing wave experiments on the PPEPL.
2. At present the suggestions for wave experiments are superficial, neither concerned with the inherent difficulties nor taking advantage of the complete facility.
3. The areas where experiments have the most promise are wave sources, wave propagation, and nonlinear interactions, and they should be implemented in that order.
4. Considerable integration of the individual proposals is both possible and desirable.
5. The facility should remain sufficiently flexible to handle new ideas as they appear, and a continuing effort should be made to solicit new ideas and approaches.
6. The major problem in the effective use of the PPEPL will be the necessity for the careful planning in terms of time, both in the overall mission concept and in the carrying out of a single experiment.
7. Detailed investigations should begin as soon as possible in the areas of antennas, both conventional and particle types, and wave-particle interaction experiments.



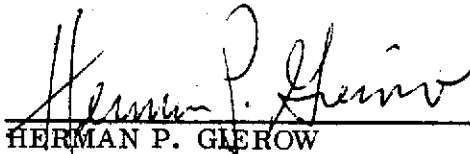
## APPROVAL

### VOLUME II - WAVE EXPERIMENTS WORKING GROUP

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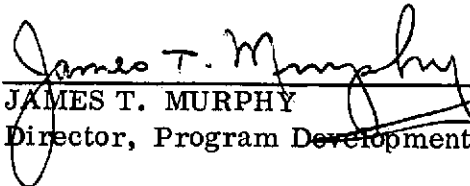
The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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